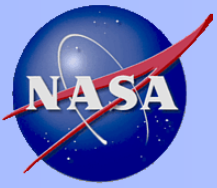


Nonproliferation Challenges in Space / Defense Technology - PANEL

Michael G. Houts, PhD

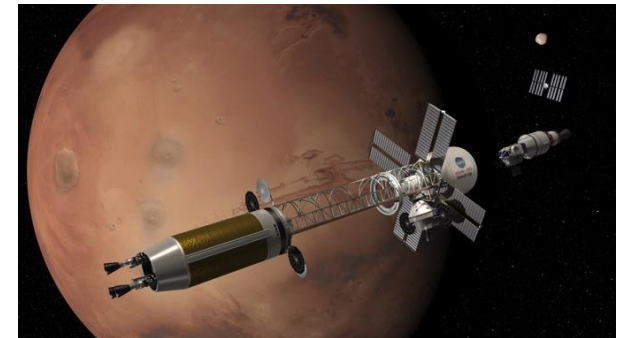
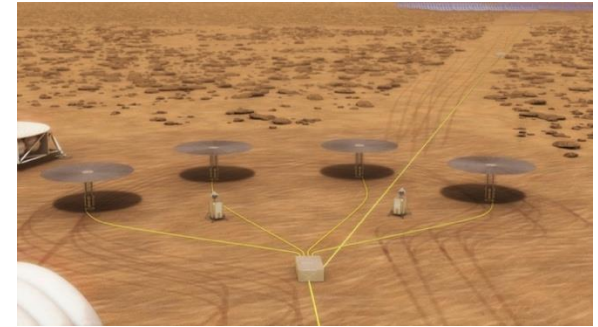
**Nuclear Research Manager, NASA Marshall Space
Flight Center**

28 September 2016

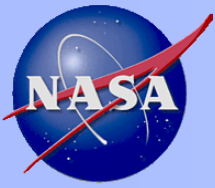


Why Space Nuclear Power and Propulsion?

- **Radioisotope Power Systems** are the most mass efficient power source (<1 kWe) for flybys, orbiters, landers, and rovers performing long-duration planetary science in the outer solar system
- **Fission Power Systems** provide the only practical option for sustained surface missions to the moon and Mars, and can provide higher power (≥ 1 kWe) for long-duration science missions to the outer planets
- **Nuclear Thermal Propulsion** enables fast Mars trip times to minimize crew exposure and can significantly reduce the number of Earth launches and the transportation element count to achieve the lowest operational costs



Nuclear Systems Provide NASA's Best Chance for Sustained Space Exploration And Low Life-Cycle Mission Cost

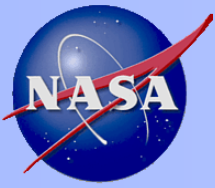


Radioisotope Power Systems

- Radioisotope Power Systems (RPS) are **ideally suited** for missions that need **autonomous, long-duration power**
 - **Proven record** of operation in the most extreme cold, dusty, dark, and high-radiation environments, both **in space and on planetary surfaces**.
- RPS provide **long-lived power** solutions for future **Planetary Decadal Science** missions
 - Mars 2020 (sample return precursor)
 - Uranus Orbiter/Probe
 - New Frontiers (Ocean-Worlds, Saturn, Lunar)
- RPS technologies offer potential to serve a wide range of missions from **Small-sat/Cube-sat to Flagship-class Science** (1-1000 W_e)
 - Thermoelectric (Pb-Te/TAGS; Skutterudite)
 - Dynamic (Stirling)
 - Radioisotope Heater Units

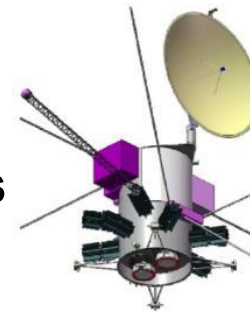


RPS have successfully powered NASA Missions for over 40 yrs. Ongoing international interest in RPS.



Fission Power Systems

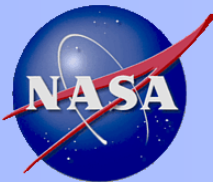
- Fission is **lowest mass** surface power option and only option that allows **global access** of the Moon and Mars
 - Fission assures **long duration, reliable power production** through multiple surface campaigns (without maintenance or resupply)
 - Fission **minimizes the risk to astronauts** during Martian dust storms and seasonal climate changes
 - Multiple, small reactor systems can be delivered on a single lander and robotically deployed for **pre-crew ISRU propellant production**
 - A modular reactor approach with multiple stand-alone units provides **redundancy/fault tolerance** and flexibility for use at multiple sites
- Fission provides a path to **high power science** missions
 - **More instruments**, larger instruments, increased duty cycles
 - **High rate communications**, real time tele-operations, in-situ data analysis, relaxed scheduling constraints
 - Sufficient on-board power to melt surface ice and **access liquid oceans** in search of extra-terrestrial life
 - **Integrates with EP** for lower launch mass, increased science access, and multiple mission targets with a single spacecraft
- Fission paves the way for **very high power** levels that aren't possible with other technologies



Example: Kuiper Belt Object Orbiter ~4 kWe
36 MMRTGs
8 Large SRGs
1 Small Fission System

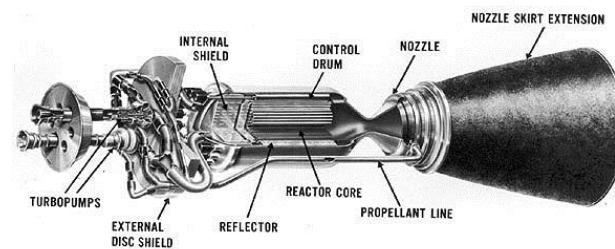


Historic and ongoing international interest in fission power systems. Over 30 space fission systems flown by former Soviet Union.



Nuclear Thermal Propulsion

- ***NTP dramatically reduces IMLEO, the required number of SLS launches and enables “affordable Mars missions” not possible using other propulsion options***
- NTP provides a 100% higher specific impulse (~900 s) than today’s best LO_2/LH_2 chemical rockets
- NTP allows short round trip opposition class Mars missions or short “1-way” transit times (<6 months) with conjunction class missions
 - Short transit times reduce crew exposure to space radiation and the debilitating effects of prolonged exposure to 0-g
 - Short trip times minimize crew logistics/consumable needs
 - NTP vehicles can be configured for artificial-g to mitigate astronaut health issues
- NTP systems can use existing (chemical) engine components and stage hardware
- NTP provides a viable option for vehicle reusability to reduce mission recurring costs
- NTP engines can be used individually or in clusters allowing multiple mission applications (e.g. Mars, Moon, Asteroid, Outer Planets) – ***with a single engine development program***



RL60 LH_2 TPA

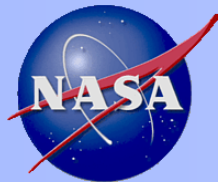


Flight Nozzles



ROVER NERVA Test Program

NTP Is the Logical Evolution In Space Propulsion To Enable Extended, Robust Human Exploration

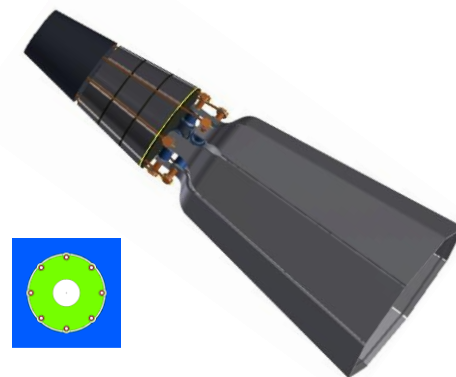


Space Fission Power and Propulsion Nonproliferation Challenges - Discussion

- The use of highly enriched uranium (HEU) almost always “helps” space fission systems.
- Nuclear Thermal Propulsion (NTP) and high power fission electric systems appear able to use $< 20\%$ enriched uranium with minimal / acceptable performance impacts.
- However, lower power, “entry level” systems may be needed for space fission technology to be developed and utilized.
- Low power (i.e. ~ 1 kWe) fission systems may have an unacceptable performance penalty if LEU is used instead of HEU.



Nuclear Thermal Propulsion



1 kWe-class “Kilopower”

Are there Ways to Support Non-Proliferation Objectives While Simultaneously Helping Enable the Development and Utilization of Modern Space Fission Power and Propulsion Systems?